Electrical Resistance Heating (ERH) Technology Coupled with Air Sparging and Soil Vapor Extraction for Remediation of MTBE and BTEX in Soils and Groundwater in Ronan, Montana.

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ABSTRACT

Gasoline from a leaking underground storage tank located in Ronan, Montana contaminated the soil and groundwater with methyl tertiary butyl ether (MTBE), benzene, toluene, ethylbenzene, xylenes (BTEX), and other compounds. Complete remediation of the site has been difficult due to the presence of fine-grained glacial lacustrine silt and clay sediments present beneath the site, and because the contaminant plume extends beneath Highway 93, a primary north-south traffic corridor in NW Montana. Common remedial technologies such as soil vapor extraction (SVE) and air sparging used historically at the site have been moderately effective in reducing contaminant levels. However, a substantial source mass of hydrocarbons located beneath the highway could not be effectively remediated. To more aggressively remediate this residual hydrocarbon source mass, we combined traditional air sparging and soil vapor extraction technologies with an innovative electrical resistance heating (ERH) technology. Twelve air sparging electrodes, six SVE wells, and eight auxiliary air sparge points were placed under Highway 93 in the source mass area. Temperatures in the treatment volume exceeded 100ºC and input power to the electrodes varied between 12 kW and 17 kW for 142 days. Soil and groundwater samples collected from the treatment zone prior to implementing the ERH demonstration project indicated high residual concentrations of MTBE and BTEX. Post groundwater and soil samples collected from the ERH treatment zone contained undetectable concentrations of MTBE and BTEX. Cost per unit volume of soil treatment may be more expensive than traditional technologies such as SVE and air sparging. However, preliminary results indicate that ERH may significantly decrease the lifespan of remediation required to treat fine-grained petroleum-contaminated sediments and thus, be competitive with current traditional technologies that require a substantially longer period of time to achieve regulatory cleanup requirements.

INTRODUCTION

The demonstration combined air sparging, soil vapor extraction, and ERH to remediate a defined volume of soil and groundwater beneath Highway 93, located within a larger gasoline plume originating from leaking underground storage tanks (USTs) located at George's Conoco. Compounds present in the gasoline released from the operating facility included methyl tertiary butyl ether (MTBE), benzene, toluene, ethylbenzene, and xylenes (BTEX). The ongoing presence of a significant light non-

Figure 1 – George's Conoco, Ronan, MT

aqueous phase (LNAPL) liquid plume has continued to generate a significant MTBE/BTEX dissolved plume. The combination of technologies used at the site targeted the removal of MTBE (a recalcitrant compound in the subsurface) in addition to the other gasoline compounds present in the treatment zone targeted by the ERH technology.

George's Conoco is located on US Highway 93 South in Ronan, Montana (Figure 1). In April 1994, a 16,000 gallon premium gasoline underground storage tank (UST) catastrophically failed. Inventory records indicated that over 2,000 gallons of gasoline was released to the subsurface within a short time period. Tank closure forms indicated that perforations and cracks were observed in weld seams and were suspected to be the cause of the subsurface release.

In May 1995, 2.5 feet of LNAPL (gasoline) was detected in a piezometer installed by the City of Ronan along the west right-of-way portion of Highway 93. Subsequent investigations revealed that an LNAPL plume (Figure 2), present on groundwater directly west of the UST basin area, had migrated under Highway 93. Based on the size of the UST and the extent of the free product plume, it was estimated that approximately 4,000 to 6,000 gallons of gasoline may have been released to the environment.

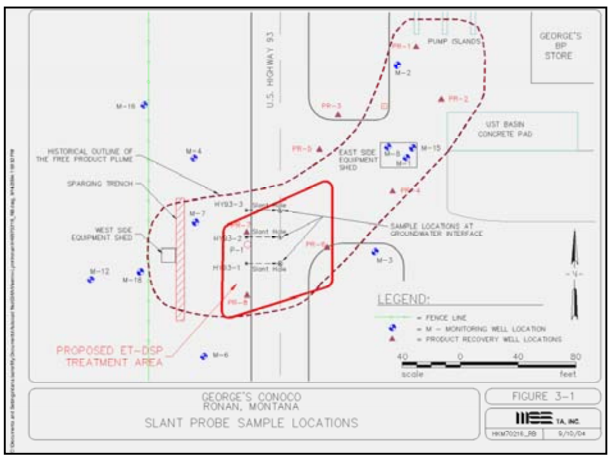


Figure 2 - LNAPL and ET-DSP Treatment Area – dashed area represents LNAPL plume

The dissolved-phase contaminant plume currently extends southwest from the release area to Spring Creek, a perennial, spring-fed stream located approximately 1,500 feet west of George's Conoco. The water table aquifer beneath the site is shallow, ranging in depth from 2 feet below ground surface (bgs) near Spring Creek to18 feet beneath Highway 93. The dominant lithology encountered in project boreholes is silt and fine sand. Significant clay layers exist in the upper 10 feet and at about 40 feet bgs. The lithology is typical of glacial lake-bed deposits, common to the Flathead Valley in which the site is located.

Since discovery of the contamination, various technologies have been used to remediate the site. Free product skimmers were first deployed in the source area to begin the removal of the free product plume. Additional product recovery wells and an 80-ft long air sparging cut-off trench were installed on the west side of the highway to stop the advance of the free product plume. Combined vacuum-assisted free product recovery and in-well sparging operations were later installed to enhance free product recovery. Through June 2003, 224 gallons of gasoline were removed by passive canisters, 1,863 gallons by skimmer pumps, and 1,369 gallons by SVE/in-well sparging for a total of 3,456 gallons. Since October 2001, no measurable free product has been detected in the original free product plume footprint. However, significant residual contamination still exists within the smear zone. Slant Geoprobe borings completed in April 2003 verified high residual petroleum contamination in the proposed treatment area and supported the decision to proceed with the demonstration.

ET-DSP TECHNOLOGY DESCRIPTION

ET-DSP^{TM} is an electrically resistive heating technology owned by the McMillan-McGee Corporation, a Canadian firm that supplies computer controlled, three-phase power to a designed grid of buried electrodes within a defined treatment volume. The technology has been used at various locations to successfully remediate sites contaminated with volatile organic compounds, but had not been previously used where MTBE was present. In the laboratory, bench scale testing determined that air sparging and SVE coupled with ET-DSP was effective at removing dissolved MTBE in water. Coupling air sparging with the ET-DSP had not been demonstrated on a field scale where MTBE was one of the principal contaminants. The George's Conoco site offered an ideal location to test the combined technologies and evaluate its effectiveness at the removal of MTBE and the other gasoline compounds.

ELECTRODE DESIGN AND LAYOUT

Static and dynamic resistivity tests conducted on the soil indicated resistivities in the range of 25 to 50 Ω·m. Typically, soils having a resistance below 100 Ω·m are suitable for electrical resistance heating. Using these results, an electrode array was designed for the proposed treatment area. The design included twelve specially designed air sparging electrodes , six soil vapor extraction wells, and eight auxiliary sparge points. The electrode grid pattern was set to match the zone of contamination under Highway 93. The north-south electrode spacing was 27.6 ft while the southwest-northeast spacing was 24.0 ft.

The electrode designed for the George's Conoco technology demonstration consisted of a 10 ft long, 8-inch diameter thin-walled steel pipe, capped at both ends. Internally, the electrodes are divided into three sections, an upper , middle, and lower, by internal packers. Each section in turn had slots cut in the steel casing to allow water and/or air to pass through into the surrounding formation. The upper and middle zones of the electrodes were configured for water injection and the lower section was designed for air sparging.

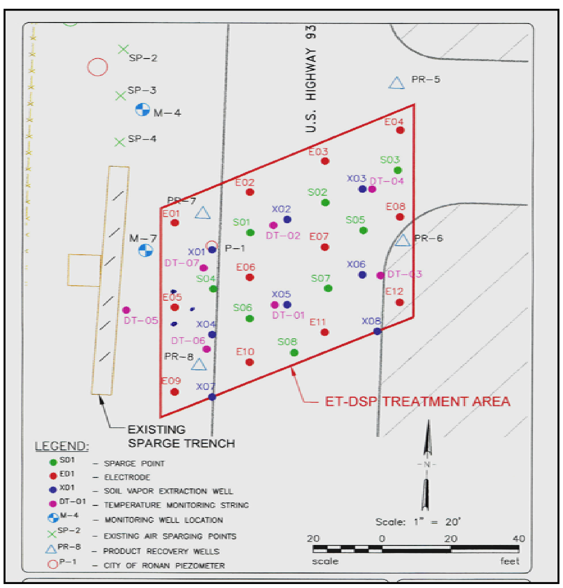


Figure 3 – ET-DSP Electrode Layout
Note that the ET-DSP Treatment area spans the width of US Highway 93.

INSTALLATION OF SPARGING ELECTRODES

The sparging electrodes were installed with a hollow stem auger boring a 12-inch hole to total design depth, knocking out the center auger plug, and filling the augers and borehole with a guar-gum slurry to keep the borehole open as the augers were removed from the hole. Once the augers were removed, a fluid-filled borehole remained, allowing the installation of the electrode and the appropriate backfill material.

Figure 4 - Electrode Installation

Typically the boreholes were drilled to approximately 27 ft bgs, allowing an extra two feet for hole slough during removal of the augers. The bottom of each 10-ft electrode was placed at the same elevation (approximately 25 ft bgs), using the centerline of the highway as the reference elevation datum.

AUXILIARY AIR SPARGE POINTS AND SOIL VAPOR EXTRACTION WELLS

Eight auxiliary air sparging points were installed within the treatment area in addition to the twelve air sparging electrodes. The auxiliary sparge points were installed using a Geoprobe direct-push rig and 2⅛-inch rod. Eight SVE wells were drilled and installed within the treatment zone to capture volatilized contaminants during the demonstration. The wells were installed using a Geoprobe rig and 4-inch solid stem augers.

TEMPERATURE MONITORING STRINGS

Seven temperature-monitoring strings were installed during the installation of the remediation system. The temperature monitoring strings, called DigiTAMs, were placed in the subsurface using a Geoprobe rig. The 2⅛-inch rods outfitted with an expendable tip were driven to a depth of 29 ft. One-inch steel conduit was joined together and placed down the inside of the Geoprobe rods. The rods were then retracted from the hole, leaving the conduit in the ground. The DigiTAMs were then placed down the conduit to the appropriate level. Locations of the DigiTAMs corresponded to areas within the treatment zone that would be the last to heat to the target temperature of 80ºC due to electricity flow patterns. Temperature sensors were spaced approximately three feet apart vertically, providing discrete depth temperature measurements.

PRE-DEMONSTRATION SOIL AND GROUNDWATER SAMPLES

During installation of remediation systems, additional soil and groundwater samples were collected in addition to the initial field characterization samples collected in April 2003. Five soil samples and three groundwater samples were collected for laboratory analyses to further establish subsurface contaminant concentrations before heating began. Samples collected from the DigiTAM holes are denoted as DT-01, DT-02, DT-03, DT-06, and DT-07. Groundwater samples were collected from DT-01 and DT-07 inside the treatment volume and DT-05 outside the treated volume, approximately 15 ft west of electrode E-05.

TRENCHING AND SYSTEM LAYOUT

All piping, wiring, and tubing for the electrodes, SVE wells, DigiTAMs, and sparge points, was placed in connecting trenches across the highway leading back to the west-side equipment building area. Before completing the west side, an 18-inch diameter by 20-ft culvert was placed in the primary east-west trench. Twenty individual air lines were run to the west side equipment building for hookup to the air sparging compressors. Eight SVE lines were run the SVE blower unit, and twelve sets of electrical leads and water hose were directed to the power delivery system (PDS) area. The trench areas were subsequently repaired with asphalt.

Figure 5 - Power, Water, and Air Line Installation

A separate 3-phase, 480 volt, 600 amp electrical service entrance was installed supply power to McMillian-McGee's PDS and corresponding electrodes. To control the power and water flow to the electrodes remotely, a telephone service was installed in the west-side equipment building. In addition to the phone service, high speed interned access via an on-site modem was also arranged allowing McMillan-McGee personnel to control their system remotely via the internet. The SVE system was powered by a Gast 5½-hp R6P155Q-50 single-phase explosion-proof regenerative blower equipped with a 55-gallon moisture separator, high-level float switch, and an in-line particulate filter. The blower was ordered with a steel enclosure in which to house the SVE equipment. The blower is rated for moving 280 cubic feet of air per minute (cfm) at free air flow and has a maximum vacuum rating at 85 inches of water. Air for the electrode air sparging system was supplied by a Gast 6066-P122 rotary vane compressor with a 5-hp single-phase motor. The compressor is rated for 55 cfm free air flow. Two solenoid-controlled headers, each supplying air to six electrodes, were assembled and controlled using a Rain-Bird ESP12LXI programmable sprinkler system controller.

OPERATION OF THE ELECTRODES

The electrodes were energized on July 11, 2003 and SVE operations following on with soil vapor extraction operations beginning July 15, 2003. Air sparging was not initiated early during the heating stage, allowing the soil and groundwater to increase in temperature to approximately 60ºC before sparging systems were activated. During the initial phase of electrode operation, the amount of electrical energy transferred from electrodes to the soil was highly variable. Due to the potential for interference from the guar-gum mixture, a bleach/salt solution was injected into each of the electrodes to break-down any remaining guar-gum around the electrode and salt (sodium chloride) was added to increase soil conductivity and induce electrical flow through the soil matrix. Soon after the electrode treatment, the total power output of the electrodes collectively doubled, indicating that the treatment was successful. To help maintain the conductivity of the soil, salt was added to the water tank supplying water to the electrodes on a routine basis through the remainder of the technology demonstration.

Once air sparging operations through the electrodes were started, it was noted that power delivery for active sparge electrodes dropped until the supply air was shut off, at which time power delivery began to increase back to pre-sparging levels. To minimize the power drops, air sparging was limited to one to two hours per zone, allowing the electrode power levels to rebound.

Water injection to all the electrodes was maintained throughout the project to facilitate power transfer into the soil and to assist with heat transfer in the subsurface material. Over the course of the project (142 days), a total of 111,008 gallons of water were injected through the electrodes, equating to an average injection rate of 0.05 gallons per minute per electrode. Assuming a treatment volume of 94,196 ft^3 (85 ft x 67.5 ft x 19 ft) and a porosity of 30%, the total water injected is equal to 0.525 pore volumes.

Power to the electrodes was shut off November 30, 2003. A total of 514,120 Kw were used during the project to heat the soil and groundwater and maintain temperatures. Input power to individual electrodes varied between 12 kW and 17 kW.

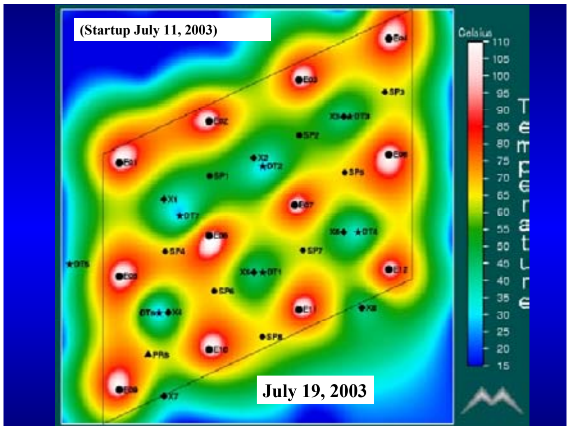


Figure 6 - DigiTam Profiles

TEMPERATURE MONITORING

Temperature monitoring was conducted in and out of the treated volume using the DigiTAM sensors. Temperature measurements were recorded hourly around the clock to monitor soil/groundwater heating progress. Despite a high failure rate of the temperature monitoring strings, enough data was recorded over time to document the soil/groundwater increase in temperature. Confirmation of soil and groundwater heating was obtained during installation of the last three DigiTAM monitors. Average temperature plots indicate relatively slow heating took place between July 11th and August 6th likely due to the effects of the guar-gum drilling fluid. Once the bleach/salt solution was injected through the electrodes and into the formation, electrical power to the electrodes could be increased. This power increase accelerated the heating and temperatures in the treatment zone generally increased from 20ºC to over 80ºC in 17 days.

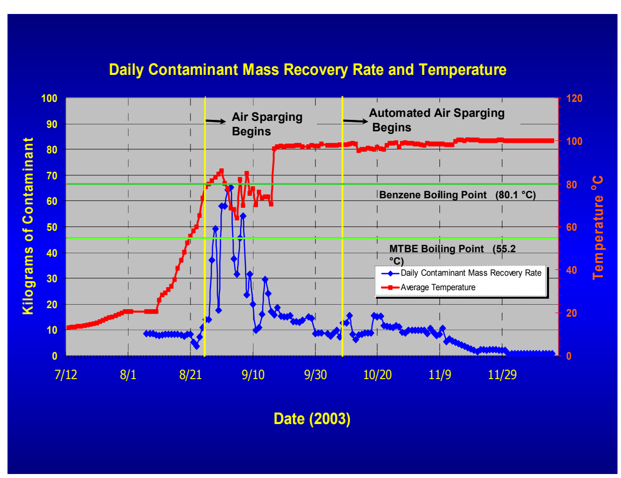
AIR SPARGING

Initial tests on the effect of air sparging on the electrodes indicated a more sophisticated controller could be installed on both systems allowing programmable pulsed air sparging. A fairly conservative pulsed sparging schedule designed to avoid disruption of power to the electrodes, started On October 8th, 2003. Each zone (two electrode zones and four auxiliary sparge zones) was sparged for one hour with a two hour break between electrode sparge zones and a one hour break between auxiliary sparge zones. More aggressive air sparging was later implemented when the treatment zone reached temperatures of over 90ºC. This schedule was maintained through the end of November when the electrodes were shut off and continued into mid-December when post-demonstration soil and groundwater sampling took place.

SOIL VAPOR EXTRACTION

The SVE capture system installed for the technology demonstration was operated nearly continuously throughout the demonstration. Routine measurements of contaminant concentrations in the SVE exhaust were made using either a MiniRae or PhotoVac MicroTip photo-ionization detector (PID) as a means to cost effectively measure hydrocarbon removal rates. Periodic tedlar air bag samples were collected from the SVE exhaust port for laboratory analysis to document actual hydrocarbon concentrations in the exhaust stream. Over the course of five months, (July 11th to December 15th) a total of 1,574 kg (approximately 560 gallons) of gasoline were removed from the treatment area under the highway.

Figure 7 – Contaminant Mass Recovery Rate



RESULTS

Soil and groundwater samples were collected from the treatment zone in December after the power was shut off from the electrodes. Analytical results indicate dramatic decreases in contaminants throughout the treatment area at the end of the demonstration period. Before the ET-DSP demonstration was conducted, groundwater contaminant concentrations in the treatment volume ranged from 13,000 to 165,000 µg/l total purgeable hydrocarbons (TPH). MTBE concentrations ranged from a low of 980 µg/l to a high of 58,700 µg/l while benzene concentrations ranged from 1,470 to 28,500 µg/l. Groundwater samples collected at nearly the same locations in mid-December 2003, approximately two weeks after the ET-DSP system was turned off, had only trace amounts of gasoline compounds well below WQB-7 standards. MTBE and BTEX concentrations were all below detection levels with the exception of a low concentration of xylene in the DT-01 @23' duplicate sample. The highest TPH concentration was 35 µg/l, well below the proposed Risk Based Screening Level (RBSL) level of 1,000 µg/l.

DISCUSSION

The subsurface contamination remaining under the highway at George's Conoco helped demonstrate that the technology could be deployed in an area with difficult access to remediate fine-grained sediments. Moreover, this demonstration relied strictly on volatilization/mobilization of the contaminants from the soil and groundwater by heat and air sparging, and SVE for subsurface capture and removal. Special attention was given to the amount of water injected through the electrodes. The volume injected was minimized to prevent contamination from being pushed out of the treatment zone.

Generally, the heating of the treated volume began slowly due to difficulty transferring electrical energy to the ground. Temperatures were only raised approximately 8ºC during the first month of operation, far slower than expected. It was suspected that the guar gum drilling fluid may have initially reduced electrical conductance to the soil. Once the electrodes were injected with bleach/salt solution to break down the guar gum drilling fluid additive and increase the electrical conductivity around the electrode, electrode current readings increased. Along with the increase in current, subsurface temperatures rose significantly. Near the end of the demonstration, average temperatures reached 100°C, well above the target level of 80°C.

COST ANALYSIS

The treatment volume was conservatively calculated to be approximately 2,771 yd^3 (74,827 ft^3) using a treatment area of 61 ft by 78 ft (in the form of a parallelogram) and an effective treatment thickness of 16 ft. Adding the value of in-kind services to the project cost and subtracting a portion of construction costs due to working on a national highway results in a project cost of $360,800. Dividing the total cost of the Ronan project by the number of yards treated results in a cost of approximately $130 per cubic yard. It should be noted that no vapor treatment was used on the Ronan SVE system, which if required, would add to project costs. Cost of electricity supplied to the electrodes was $24,404 and used a total of 514,120 kw/hr of power at an average cost of $0.0475 per kw/hour. Electrical costs to run the SVE and air sparging systems were approximately $1,000.

CONCLUSIONS

- Post-demonstration soil and groundwater samples collected from the same general pre-demonstration sampling locations found contaminant concentrations reduced to non-detect or slightly above detection levels.

- ERH can be successfully implemented beneath major highways or other public areas with minimal disruption to the public. A total of 1,574 kg (equivalent to 560 gallons) of gasoline was recovered from under the highway over the course of the demonstration, despite the fact that relatively aggressive remedial systems were employed along both sides of the highway prior to the project.

- Air sparging when used in conjunction with ET-DSP™, has a positive effect on the volatilization and removal of contaminants. Contaminant concentrations in the SVE exhaust increased dramatically immediately following the start-up of air sparging operations. Air sparging operations had significant effects on the electrode operation and temperature distribution in the treatment zone. Sparging through the electrodes caused a drop in the amount of electrical current being passed into the ground, likely due to the drying action of the air passing through the formation. Sparging activity caused sharp temperature swings in the DigiTAM monitoring strings, indicating that liquids and gasses were being pushed around in the subsurface, likely assisting in the volatilization and removal of contamination.

- Continuous air sparging was unnecessary. Pulsed sparging for one to two hours per zone, twice daily, appeared to be effective. The use of both sparging electrodes and individual sparge points along with programmable air flow controllers in the system design provided flexibility in air sparging operations.

- Total cost of the demonstration was determined to be $360,800, based on actual costs, in-kind services, and other funding sources. Based on a treated volume of 2,771 cubic yards, the cost to treat a cubic yard was calculated to be $130.

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